

Observation of Persistent Currents in Finely Dispersed Pyrolytic Graphite¹

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The trapped magnetic flux in the finely ground pyrolytic graphite sample annealed at 670 K in air has been observed. Flux trapping occurs on cooling of the sample from room temperature to 10 K in a magnetic field of 1 T. The magnitude and sign of the induced trapped moment remain unchanged when the applied magnetic field is varied within ± 1 T at $T = 10$ K. The trapped magnetic flux is manifested in the displacement of the magnetization curve relative to that of the sample cooled in zero field. Displacement magnitude gradually decreases with the temperature increase up to 350 K, not reaching zero. The set of experimental observations probably reflects the presence in the sample of a granular high-temperature superconducting phase.

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Recently, a lot of the attention has been paid to the studies of strongly correlated phenomena, such as ferromagnetism and superconductivity, in various forms of carbon, including graphite [1–13]. In the past, a large number of theoretical works has been published devoted to possible manifestations of the superconductivity in graphite; however, the number of experimental studies remains small. The list of published experimental results includes the reports on a superconducting phase formation in graphite on its doping with phosphorus [7], sulfur [8], water [9], in contact with alcohol [10], as well as in disordered samples [11, 13] or on its incorporation into polymers [12]. In many cases, the superconducting phase had a granular structure. Indications of the superconductivity were found in multiwall carbon nanotubes [14–16], fullerenes C_{60} [17], toroids C_{576} [18] and other carbon structures and constituents [2, 3, 15] where the insistent currents and trapped magnetic flux were induced by an applied magnetic field. Performed experimental studies suggest that many factors such as defects, impurities and structural instabilities affect strongly the superconductivity and magnetism of graphite.

It has been predicted recently that at the interface between two slightly twisted graphite sheets structures with flat energy bands can form in which high-temperature superconductivity is possible [4]. The number of such defect structures in crystalline graphite is obviously small. Therefore, in the present work the samples of finely ground highly oriented pyrolytic graphite were studied that were annealed after grind-

ing to increase the formation probability of specific interface boundaries like those considered in [4].

Detection as well as an experimental verification of small inclusions of superconducting phase in powder samples is not a trivial task. For an object that undergoes a transition to a superconducting state throughout the volume, the standard methods are the resistivity measurements and the observation of the Meissner effect. However, in the case of a granular sample, the magnitude of the contribution to the conductivity will be proportional to the fraction of the superconducting phase. In magnetic measurements, the effect may be smeared out by the distribution of the critical temperatures; the task is further complicated if most of the sample volume has a pronounced diamagnetic response (the case of graphite [19]). In both cases, careful extraction of small corrections to the effects with large intrinsic amplitudes has to be performed. Correctness of such small contribution extraction often gives rise to reasonable doubts [20].

This paper presents the results of the investigation of the magnetic properties of the samples prepared from highly oriented pyrolytic graphite (HOPG). Collected data indicate magnetic flux trapping and occurrence of the persistent currents up to the temperatures higher than the room temperature. The magnitude and the character of the observed effects are such that they manifest themselves directly even against the background of a large diamagnetism of graphite and the presence of a weak ferromagnetic response.

The samples for investigation were obtained from a HOPG crystal (Advanced Technical Center, Moscow) by grinding in an agate mortar for 12 h. To exclude

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